An AUV-Based Investigation of the Role of Nutrient Variability in the Predictive Modeling of Physical Processes in the Littoral Ocean

Kent A. Fanning
College of Marine Science
University of South Florida
St. Petersburg, FL 33701
phone: (727) 553-1594   fax: (727) 553-1189   email: kaf@marine.usf.edu

John Walsh
College of Marine Science
University of South Florida
St. Petersburg, FL 33701
phone: (727) 553-1164   fax: (727) 553-1189   email: jwalsh@marine.usf.edu

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http://www.marine.usf.edu

LONG-TERM GOALS

Our long-term goal is to explore and test the potential effectiveness of low-level nutrient concentrations (nitrate, nitrite, and ammonia) as descriptors of geophysical fields and tracers of physical processes in oligotrophic coastal waters, with particular attention to adapting our laboratory sensor of these nutrients for use in an AUV. The resulting nutrient data are to be incorporated into prognostic physical-biogeochemical models in a feedback mode.

OBJECTIVES

This past year is the second year of a two-year project, and the objectives pursued were derived in part from the research proposed for that second year. Changes and additions to those objectives were made because of several factors: (1) funding-agency support of ship time, (2) completion of research started in the first year, and (3) new technical possibilities that appeared in the first year.

Objective 1: A new Florida Shelf Lagrangian Experiment (FSLE 7) was planned that would be an improvement on the previous experiment (FSLE 6). It would be 50% longer to determine the lifetime of high-ammonia boluses in oligotrophic shelf waters more accurately. We know that the boluses last at least 4.3 days. It would also occur in the spring to round out our seasonal studies of the boluses.

Objective 2: Analysis of data from FSLE cruise (s) leading to modeling efforts

Objective 3: The development of software specifically designed to monitor data acquisition during continuous field surveys such as FSLE cruises in such a way that the effectiveness of the surveys can be maximized. In order to describe the number, shape, dispersion, and drift of surface-water parcels with ammonia or other nutrient maxima, we need to know the positions and values of the actual concentrations being measuring in as fast as possible. Then the survey protocol can be adjusted to track those parcels very precisely in near-real time.

Report Documentation Page

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Objective 4: To finalize the modifications to the AUV nutrient sensor that are required to achieve an analytical detection limit adequate for the nanomolar concentrations of nitrate, nitrite,and ammonia found in oligotrophic shelf waters.

APPROACH

Objective 1: FSLE 7 was planned for three weeks instead of the usual two weeks for previous FSLE cruises. NOAA was to provide ship time support, either aboard the *R/V Brown* or by providing funds for the *R/V F Walton Smith*. Since that support did not materialize, the cruise had to be delayed a year.

Objective 2: The cruise FSLE 6 occurred in November, 2002, after last year's Annual Report was submitted. Just like the earlier FSLE's 3-5, FSLE 6 took place in the Control Volume in 25-35 m of water to the west of Sarasota, Florida. A surface region that contained boluses or "pulses" of high-ammonia seawater was injected with SF_6 to track its motion and mixing. The resulting surveys assessed the degree to which the ammonia "pulses" followed SF_6 and permitted comparisons between autumn ammonia pulses and springtime pulses, such as found on FSLE 5 in the same location. Two aspects of the FSLE 6 protocol were different. First, our two identical nutrient sensors for nitrate, nitrite, and ammonia (Masserini and Fanning, 2000) were run sequentially (instead of simultaneously) so that we could sample surface seawater through the flowing seawater system continuously for up to 24 hours along a survey track. Thus we could measure diurnal variations in ammonia within the SF_6-labeled region containing ammonia pulses. Second, chlorophyll-a and phaeopigments were determined. Chl_a was measured in the flowing seawater and in hydrocasts, and both biological parameters were measured in hydrocasts. The data analysis of FSLE 6 was conducted this year and compared diurnal variations in the pulses and biological parameters. In addition, initial biochemical models were attempted. Key individuals in the FSLE 6 data acquisition and analysis: K. Fanning and R. Masserini of USF (ammonia/nutrient determinations) and R. Wanninkhof and K. Sullivan of AOML-NOAA (SF_6 injection and measurement). Key individuals in the modeling are J. Walsh, R. Weisberg, and B. Darrow from USF.

Objective 3: The required customized software was designed to calculate nutrient concentrations from standardization curves, keep track of the acquisition times and positions of all samples, and then plot the geographic distribution of actual nutrient concentrations as soon as the fluorescent detectors (either our laboratory version or our AUV version) have supplied the analytical signals. Individuals important to this work were R. Masserini, J. Patten (software engineer at The Center for Ocean Technology (COT) within the USF's College of Marine Science), and K. Fanning, principal investigator.

Objective 4: The problem with the AUV version of our nutrient sensor is that detection limits are too high for oligotrophic shelf waters because the signal-to-noise ratio is too low. Our basic approach was to raise that ratio to an acceptable level. Key individuals involved are: R. Masserini and K. Fanning (USF Marine Science) and R. Carr of USF-COT

WORK COMPLETED

Objective 1: none, see above

Objective 2: The motion of the high-ammonia pulses relative to the injected and co-located SF_6 was evaluated. Also, a complete sample-by-sample comparison of dissolved nutrients (especially ammonia), SF_6, and biological parameters was completed for FSLE 6, permitting the determination of

simultaneous diurnal variations in all of them. Two publications – Walsh et al. (2003a) and Darrow et al. (2003), which utilize data generated by our research cruises, simulate the physical and biological contributions to the functioning of the West Florida Shelf ecosystem.

Objective 3: The software is completed. An early version was tested in the laboratory and on a field study (FSLE 6) and then improved to better its performance even more.

Objective 4: In an effort to bring the detection limits of the AUV sensor closer to that of the laboratory based system we had made the following changes. Incorporate a 64 MHz analog to digital converter to synchronize light pulses with digitization of emitted fluorescent light. This required reengineering the analog based multiplexing of the 1000 V flash lamp power supply to a microcontroller based system. Incorporation of this technology allows for advanced mathematical treatment of the detector outputs to filter ambient noise and focus on the fluorescent signal of interest.   Also it allowed us to decrease the flash rate to increase light pulse stability. Additionally we optically isolated grounds and rerouted power to key components to reduce the amount of noise induced into the electronics by the electro-magnetically induced (EMI) noise generated by the flashlamps and physically isolate noise generating systems to the greatest extent possible. The majority of the required design changes not completed last year were completed this year. The analog section was redesigned to eliminate discrete component peak detection, utilizing an input op-amp for filtering and a high-speed differential driver straight to an analog to digital converter. Peak detection, power estimation, integration and other filtering can now be performed in the digital domain allowing great flexibility in signal processing. Also, all grounds were rerouted and separated. The high voltage power supply was isolated from other electronics with a connection back at the battery power source as an additional measure to reduce noise. The new design incorporates a 14-bit 64 MHz converter. In order to couple this high speed data acquisition to the 16 MHz controllers used in the nutrient sensor, the analog to digital output data are now dumped into high speed first in first out (FIFO) for collection. Also, a field programmable gate array (FPGA) now controls the high-speed data acquisition and sample counting. High-speed differential PECL drivers, with high side and low side signal terminations, have been utilized to maintain clock duty cycle and to distribute and localize currents to reduce electromagnetic interference.

RESULTS

Objective 1: none see above

Objective 2: Compared to FSLE 5, the dispersion of SF_6 and high-ammonia pulses were much less over the course of FSLE 6, at least during the week immediately after SF_6 injection. However, the FSLE 6 pulses remained within the SF_6 patch and essentially drifted along with it in a fashion similar to that observed during FSLE 5 (Fanning et al., 2003). Interestingly, ammonia concentrations in the pulses varied on a reasonably regular basis (Figure 1) and, when compared to Chl_a concentrations in the same waters, varied with approximately the same short-term time scale as the Chl_a – namely one cycle every 12-to-24 hours. This similarity suggests that the variations in ammonia may be linked to biotic variations. However, the longer term trends in the two records do not always match – see the record from JD 311 to JD 316, implying an independence of one parameter from the other. Obviously, these temporal trends need to be examined further by further data analysis (e.g., applying error limits to the data in Figure 1), by additional field studies (FSLE cruises), and by additional modeling efforts in which physical and biological terms can be compared for relative importance. In preliminary modeling efforts over the last year (based on ONR support), a series of both three-dimensional (3-d,
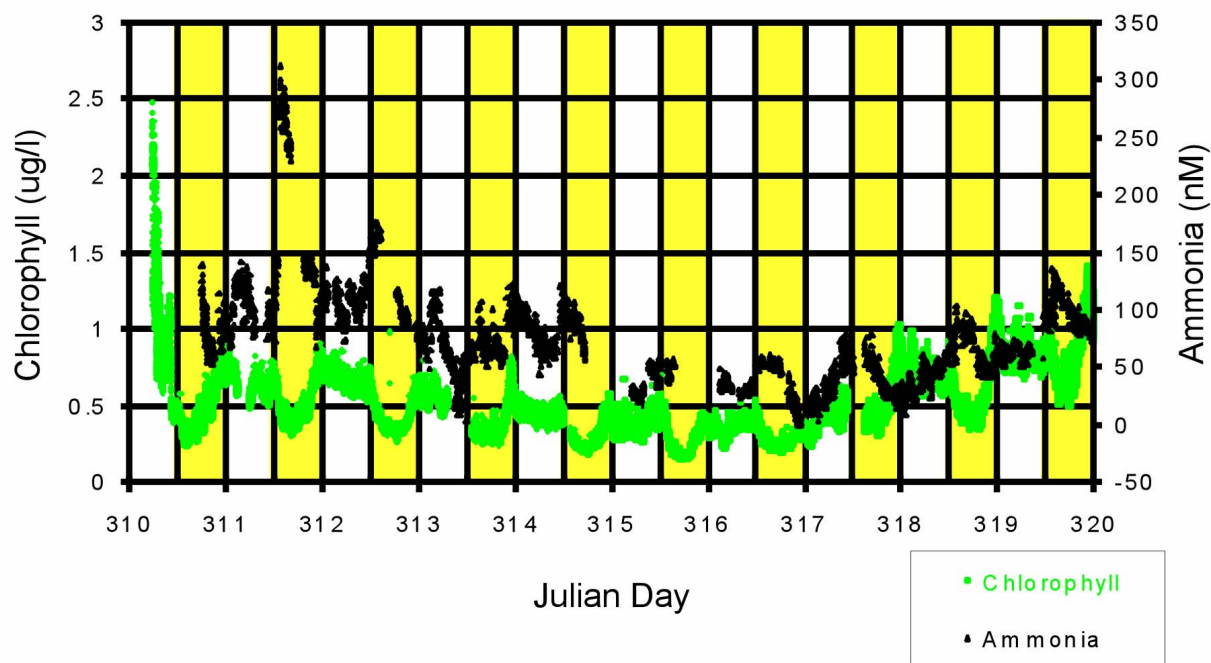
Figure 1. Co-located concentrations of ammonia and chlorophyll-a in surface waters of the West Florida Shelf west of Sarasota, Florida, during zigzag surveys of a region of oligotrophic shelf water containing high-ammonia boluses and labeled with a SF₆ dispersion tracer in November, 2002, during FSLE 6. [The data points represent actual concentrations in seawater brought through a port in the hull of the research vessel at 1-3 m depth, passed through a fluorometer for Chl_a determination, and then sampled for ammonia by the Masserini and Fanning (2000) method. Concentration data are plotted against sampling time for ammonia in Julian Days]

Walsh et al. 2003) and one-dimensional (1-d, Darrow et al., 2003) coupled physical and biochemical models (published or in press) deal with such simulation analyses of our validation field data. We find that motion, both of water in aphotic regions and of fish within the euphotic zone - i.e. the supply processes - rather than processes of *in situ* utilization, may be the most important control factor of signals of persistent recycled nitrogen like ammonia on the West Florida Shelf (Fanning et al., 2003). In the 3-d model, bioturbation coefficients, K_b, were a function of bottom water temperature, supplied from the coupled USF version (Weisberg and He, 2003) of the Princeton Ocean Model (POM).

Objective 3: The software is an advanced GUI-based application in which incoming analytical signals are converted to near real-time concentration values for nitrate, nitrite, and ammonia and used in the color-coded plotting of these concentrations in latitude-longitude space. This is as close to real time as will ever be possible; it takes time (~200 sec) for a sample to go through the analytical system, react with reagents, and flow through the detectors. After that, only microseconds are required before the concentrations and dwell-time-corrected latitude and longitude for a sample are determined. Concentrations are automatically calculated using calibration factors and blank corrections from the

last calibration run/file. The calibration file associated with a run can be edited later, for instance using a calibration run that follows a survey run. All peak markers used to determine peak heights and blanks that are then used to calculate concentrations can be adjusted "on the fly" (rarely necessary since we have developed robust algorithms for the placement of peak markers). The diurnal time variations in Figure 1 discussed under Objective 2 (above) would not have been possible without this software since the field plots of nutrient distributions for each survey were used to plan the next one.

Objective 4: Initial tests on a one-channel prototype of the new electronics look quite promising. The high voltage power supply for the xenon flash lamp was triggered with the new electronics and the photomultiplier output was captured via the new high-speed data acquisition system. This yielded very good results after application of a boxcar-averaging scheme using just a few samples. We have combined the electronics with the actual Masserini and Fanning (2000) analytical system to determine gain requirements and the appropriate mathematical filters for the signal waveform to minimize noise while optimizing and maintaining high-speed peak detection capability. To account for pulse-to-pulse variation in the output of the xenon flash lamps, we found it necessary to incorporate a second PMT into the optical system to collect the background light intensity data for normalizing the fluorescence output proportional to analyte. Also, a differential measurement printed circuit board (PCB) has been prototyped, designed, built, tested, and revised that greatly reduces the influence of EMI in the detection electronics. This PCB is a two-channel system; one channel for the fluorescent signal and the second for the lamp output background signal. The differential measurement was shown to reject EMI and yield the best possible input signal into the high-speed data acquisition software discussed under Objective 3.

IMPACT/APPLICATIONS

The software we have devised to provide nutrient distributions at sea can be readily adapted to any analytical system where a color-coded real-time readout of analyte concentration in latitude-longitude space is desired. Any analog signal from a detector could be input into the software, and, with the appropriate peak picking or integration algorithm and sample dwell-time, a nearly instantaneous concentration value and position for a sample can be determined, color-coded, and plotted along a cruise track. All scales are easily adjustable, and an effort has been made to make the software reasonably intuitive. An analyst who has operated automated analytical systems would quickly comprehend the controls and menus and in a short period of time be able to use it with confidence. Statistical data for quality control is automatically logged and updated. Plots of regressions and residuals for standard runs are automatically created and contaminated calibrants (should they occur) can be easily removed by simply clicking on the questionable data point and selecting the appropriate option from a pop-up menu. All changes by the user that alter the response factors and/or blank values are automatically reflected in the quality control logs. *What once took a graduate student months to process is now done almost instantaneously and can be adapted for use in an AUV*!

RELATED PROJECTS

With support from N000149810158, Bob Weisberg, (http://ocg6.marine.usf.edu/) is applying a primitive equation model to observed West-Florida-shelf current fields. It is an adaptation of the POM with topography-following vertical sigma coordinates and horizontal orthogonal curvilinear coordinates. Far-field shelf-break forcing is also being examined. It will provide boundary values for the modeling of nutrient/SF_6 data, and the resulting nowcasts and forecasts can be calibrated by our measured distributions. With support from N000140110041, Paula Coble

(http://www.marine.usf.edu/mfl/index.html) is providing CDOM data related to the spectral attenuation of light and possible photolysis yields of labile nitrogen from terrestrial CDOM between the Mississippi River and the Florida Keys. With support from N000149710006, Ken Carder is using remote sensing algorithms to provide initial conditions of models of the role of Saharan dust deposition and nitrogen fixation by *Trichodesmium* in the nitrogen economy of the WFS. Finally, with support from N000149615020, Tom Hopkins is providing corroborative HRS data on the role of zooplankton in WFS bloom initiation and termination within the Control Volume on the West Florida Shelf where FSLE studies 3-5 were performed and FSLE 6 will be performed.

REFERENCES

Darrow, B.P., J.J. Walsh, G.A. Vargo, R.T. Masserini, K.A. Fanning, and J.-Z. Zhang. 2003. A simulation study of the growth of benthic microalgae following the decline of a surface phytoplankton bloom. Cont. Shelf Res. [in press].

Fanning, K.A., R.T. Masserini Jr., J. Walsh, and R. Wanninkhof. 2003. Ammonia: a surprising tracer of oligotrophic coastal waters (in prep., to be submitted to Nature).

Masserini, R.T., Jr. and K.A.Fanning. 2000. A Sensor Package for the Simultaneous Determination of Nanomolar Concentrations of Nitrite, Nitrate, and Ammonia in Seawater by Fluorescence Detection. Marine Chemistry, 68, 323-333

Walsh, J.J., R.H. Weisberg, D.A. Dieterle, R. He, B.P. Darrow, J.K. Jolliff, K.M. Lester, G.A. Vargo, G.J. Kirkpatrick, K.A. Fanning, T.T. Sutton, A. E. Jochens, D.C. Biggs, B. Nababan, C. Hu, and F. E. Muller-Karger. 2003a. The phytoplankton response to intrusions of slope water on the West Florida shelf: models and observations. J. Geophys. Res. 108, 3190, doi: 10.1029/2002JC001406

Weisberg, R.H. and R. He. 2003. Local and deep-ocean forcing contributions to anomalous water properties on the west Florida continental shelf. J. Geophys. Res. 108, 3184, doi: 10.1029/2002JC001407.

PUBLICATIONS

ONR-supported 2003 Publications and Symposia Proceedings:

Cannizzaro, J.P., K.L. Carder, F.R. Chen, J.J. Walsh, Z. Lee, C. Heil, and T. Villareal. 2003. A novel optical classification technique for detection of red tides in the Gulf of Mexico. Proc. X Intern. Symp. Harmful Algal Blooms, Oct 21-25, 2002. St. Pete Beach, FL, K.A. Steidinger (ed.), [in press].

Darrow, B.P., J.J. Walsh, G.A. Vargo, R.T. Masserini, K.A. Fanning, and J.-Z. Zhang. 2003. A simulation study of the growth of benthic microalgae following the decline of a surface phytoplankton bloom. Cont. Shelf Res. [in press, refereed].

Havens, J. J. C.A. Heil, D. Hollander, G.A. Vargo, D. Ault, S. Murasko, and J.J. Walsh. 2003. Isotopic constraints on nutrient sources supporting the 2001 *Karenia brevis* bloom. Proc. X Intern. Symp. Harmful Algal Blooms, Oct 21-25, 2002. St. Pete Beach, FL, ed. K.A. Steidinger [in press].

Hu, C., F. E. Muller-Karger, K. L. Carder, J. J. Walsh, G.A. Vargo, C.A. Heil, and J.J. Jollif. 2003. Partition of ocean color into chlorophyll and dissolved matter: A case study on the West Florida Shelf. Geophys. Res. Lett. [refereed].

Jolliff, J.K., J.J. Walsh, R. He, R.H. Weisberg, A. Stovall-Leonard, R. Conmy, P.G. Coble, C.A. Heil, B. Nababan, H. Zhang, C. Hu, and F.E. Muller-Karger. 2003. Dispersal of the Suwannee River plume over the West Florida shelf: simulation and observation of the optical and biochemical consequences of a "flushing event". Geophys. Res. Lett. [in press, refereed].

Kirkpatrick, G.J. and J.J. Walsh. 2003. ECOHAB/HyCODE studies of the West Florida shelf Cont. Shelf Res. (special volume) [in press, refereed].

Lenes, J.M., J.J. Walsh, D.B. Otis, and K.L. Carder. 2003. Iron fertilization of *Trichodesmium* off the west coast of Barbados: A one-dimensional numerical model. Deep Sea Res. [refereed].

Milroy, S.P., D.A. Dieterle, R. He, G.J. Kirkpatrick, K.M. Lester, K.A. Steidinger, G.A. Vargo, J.J. Walsh, and R.H. Weisberg. 2003. A three-dimensional biophysical model of *Karenia brevis* dynamics on the West Florida shelf: a preliminary look at physical transport and zooplankton grazing controls. Cont. Shelf Res.

Vargo, G.A., C.A. Heil, D.N. Ault, M.B. Neely, S. Murasko, J. Havens, K.M. Lester, K. Dixon, R. Merkt, J.J. Walsh, R.H. Weisberg, and K.A. Steidinger. 2003. Four *Karenia brevis* blooms: a comparative analysis. Proc. X Intern. Symp. Harmful Algal Blooms, Oct 21-25, 2002. St. Pete Beach, FL, K.A. Steidinger (ed.), [in press].

Walsh, J.J. and K.A. Steidinger. 2003. ECOHAB:Florida. Proc. X Intern. Symp. Harmful Algal Blooms, Oct 21-25, 2002. St. Pete Beach, FL, K.A. Steidinger (ed.), [in press].

Walsh, J.J., R.H. Weisberg, D.A. Dieterle, R. He, B.P. Darrow, J.K. Jolliff, K.M. Lester, G.A. Vargo, G.J. Kirkpatrick, K.A. Fanning, T.T. Sutton, A. E. Jochens, D.C. Biggs, B. Nababan, C. Hu, and F. E. Muller-Karger. 2003a. The phytoplankton response to intrusions of slope water on the West Florida shelf: models and observations. J. Geophys. Res. 108, 3190, doi: 10.1029/2002JC001406 [published, refereed].

Walsh, J.J., D.A. Dieterle, W. Maslowski, and T.E. Whitledge. 2003b. Decadal shifts in biophysical forcing of marine food webs in the Arctic: numerical consequences. J. Geophys. Res. [in press, refereed].

Walsh, J.J., G.J. Kirkpatrick, B.P. Darrow, G.A. Vargo, K.A. Fanning, E.B. Peebles, C.A. Heil, J. Havens, and K.A. Steidinger. 2003c. Fish farming by *Karenia brevis*: a nutrient source for large red tides. Cont. Shelf Res. [refereed].

Walsh, J.J., D.A. Dieterle, B.P. Darrow, S.P. Milroy, J.K. Jolliff, J.M. Lenes, R.H. Weisberg, and R. He. 2003d Coupled biophysical models of Florida red tides. Proc. X Intern. Symp. Harmful Algal Blooms, Oct 21-25, 2002. St. Pete Beach, FL, K.A. Steidinger (ed.), [in press].